The Cytological Effects of Low-Intensity Radiation[1]

Karl Sax

The Arnold Arboretum, Jamaica Plain, Massachusetts

The effects of low intensities of ionizing radiation are of interest in relation to the incidence and nature of induced mutations. The effects of long-continued radiation at low intensities are also of interest from the standpoint of atomic energy programs in times of peace or war. Little is known about the cumulative effects of exposure over long periods of time.

The early work by Muller and by Timofeeff-Ressovsky showed a linear relationship between x-ray dosage and mutation frequency in *Drosophila*. It was also found that the induced mutation rate was independent of radiation intensity. From these observations it was concluded that the x-ray-induced mutations are produced by single "hits," and that there is no threshold effect. Spencer and Stern (*2*) found no increase over the spontaneous mutation rate by irradiating *Drosophila* for 21 days at 2.5 r/day, but later experiments by Uphoff and Stern (*3*) indicated that low intensities are effective.

Further studies on x-ray-induced mutations by Stadler showed that such "mutations" are usually, if not always, caused by aberrations of the chromosomes. The aberrations usually involve deficiencies, but inversions and translocations may also produce "mutations." The frequency of simple deletions is directly related to x-ray dosage, but the aberrations involving two breaks—rings, dicentrics, translocations, and presumably inversions—increase in frequency in proportion to the square of the dosage when the time of exposure is constant.

At very low intensities of irradiation, the simple deletions constitute the great majority of all chromosome aberrations in *Tradescantia*. A total dose of 150 r of γ rays at an intensity of 0.05 r/min produced 5% of deletions, but only 0.6% of translocations and dicentrics in Tradescantia chromosomes. The same dose of x-rays at an intensity of 40 r/min produced essentially the same percentage of simple deletions, but 10% of rings and dicentrics.

Although low intensities of ionizing radiation are less effective, the accumulation of aberrations and lethal "point mutations" over a long period of time could be just as deleterious as smaller doses given at high intensities. The effects of long-continued exposure of low-intensity radiation have been studied by exposing potted plants of *Tradescantia paludosa* (Clone 3) to low intensities of γ radiation for several months. The results are shown in Table 1.

The control plants show considerable variability in spontaneous chromosome aberrations. The average percentage of chromosome breaks for the total of all controls was .08%. If, however, plants removed from the radium beam for 4 weeks or longer are included among the controls, the spontaneous aberration frequency is reduced to .06% of breaks.

TABLE 1

CHROMOSOME ABERRATIONS AND POLLEN STERILITY INDUCED BY 1.7 R/DAY OF γ RADIATION

Weeks of exposure	Controls		Irradiated	
	No. chromosomes	% breaks	No. chromosomes	% breaks
1	2,052	.10	7,380	.06
2	1,480	.07	5,010	.18
3	2,190	.14	5,460	.57
4	2,280	.09	5,820	.53
6	2,166	.09	4,830	.33
11	4,350	.07	2,322	.52
22	6,180	.05	3,300	.52
Total	20,698	.08 (av.)	21,732*	.49 (av.)

* Total for 3–22 weeks.

Continued exposure to 1.7 r of γ rays/day increased the aberration frequency at the end of the second week, and a continued increase at the end of 3 weeks' exposure. There was, however, no further increase in aberration frequency following continued exposure. At the end of 22 weeks the plants had received 262 r of γ radiation, but showed only 0.5% of breaks in the microspore chromosomes. This dose of x-rays, given in a few minutes at the prophase stage, would have produced more than 30% of breaks.

The increase in aberration frequency during the first few weeks of exposure is due to the accumulation of aberrations produced during microspore development. During the fall and winter months, when this study was made, the duration of the microspore cycle from meiosis to the division of the microspore nucleus is about 12 days. Aberrations produced at late meiosis may be passed on to a viable microspore, but most detectable aberrations produced at the first meiotic division or earlier are not recovered at the microspore nucleus division, because of lethal deficiencies that prevent microspore development.

The failure of a cumulative effect of the γ radiation could be attributed to the screening-out of chromosome aberrations at meiosis and/or to differential development of normal and aberrant cells in premeiotic development. These alternatives were tested by a study of pollen sterility and by a chromosome analysis of plants removed from the field of radiation. Plants that had received 1.7 r/day for 2 months were removed from the beam, and microspore chromosomes were examined during subsequent weeks. The data are shown in Table 2. There was some decrease in chromosome aberrations after a week, and after the third week the chromosome aberration frequency was reduced to the spontaneous level. If the lack of this cumulative effect is due only to the screening of chromosome aberrations at meiosis, the pollen sterility should increase with continued exposure, and eventually the plants should be completely sterile. Pollen sterility counts were made at weekly intervals from plants exposed to 1.7 and 8.0 r/day for 12 weeks.

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TABLE 2

FREQUENCY OF CHROMOSOMAL ABERRATIONS AFTER REMOVING PLANTS FROM 2 MONTHS' EXPOSURE TO 1.7 r OF γ RADIATION. RECOVERY PERIODS, 1 WEEK TO 4 MONTHS

Recovery time	No. chromosomes	Chromatid breaks	Chromosome breaks	Total % breaks
1 week	3,150	7	3	.32
2 weeks	4,320	4	0	.09
3 "	5,760	4	4	.14
4 "	2,910	1	0	.03
6 "	1,800	0	0	.00
4 months	6,180	3	0	.05

Counts from control plants were made at the same time. The normal sterility varies considerably, presumably in response to environmental conditions of temperature and light, and ranged from 5 to 14%. The percentage of sterility in the controls was deducted from the sterility of the exposed plants to give the net sterility due to radiation effects. The data are shown in Table 3.

TABLE 3

POLLEN STERILITY INDUCED BY CONTINUOUS RADIATION AND THE RECOVERY OF POLLEN FERTILITY SUBSEQUENT TO 5 WEEKS OF EXPOSURE

No. weeks exposure	Net pollen sterility			
	During exposure		After exposure	
	1.7 r/day	8 r/day	1.7 r/day	8 r/day
1	6	−1	28	42
2	11	4	28	42
3	29	3	18	48
4	37	14	18	56
5	24	35	4	37
6	35	37	3	33
7	31	50		50
8	42	53		53
9	25	48		18
10	27	43		9
11	21	55		9
12				2
13				0

At an intensity of 1.7 r/day the pollen sterility increased during the first 3 weeks and then leveled off at about 30%, although there was considerable variability from week to week. At 8 r/day the maximum sterility was not reached until about the sixth or seventh week, presumably in consequence of the retarding effect of the greater amount of radiation; but after 6 weeks' exposure, the pollen sterility remained at about 50% during the subsequent weeks. At this intensity there was considerable inhibition of floral development, and very few flowers were produced after 2 months of exposure.

After 5 weeks of exposure some of the plants were removed from the field of radiation in order to see how long the pollen sterility would continue. At 1.7 r/day the pollen fertility at 5 weeks after exposure was practically normal. At 8 r/day the plants did not recover normal fertility until about 12 weeks after removing them from the beam of γ rays. This greater delay in recovery is attributed to the greater retardation of growth of the plants at the higher intensity.

The lack of a cumulative effect in the production of microspore chromosome aberrations and pollen fertility after several weeks' exposure to low intensities of γ rays, and the recovery of normal microspore chromosomes and pollen fertlity after the plants are removed from the radiation field, indicate that cells containing chromosome aberrations do not continue to divide or are outgrown by the normal cells. Earlier work (*1*) has shown that, if sufficient radiation is given to produce chromosomal aberrations in nearly all cells, the plant dies. At low intensities of radiation many cells are not permanently affected, and presumably these cells are the ones that produce the normal microspore chromosome complements and the fertile pollen grains. Continuous exposure to several roentgens per day does not seriously reduce pollen fertility or seed set, although it is possible that some deleterious mutations may appear in later generations. The fact that both chromosome aberrations and pollen sterility level off after a few weeks of exposure indicates that the plants can survive and reproduce after months, or perhaps even years, of exposure.

These results indicate that Tradescantia plants, and probably most plants, can survive continuous radiation at the rate of several roentgens per day. Unfortunately, they cannot be expected to apply to the higher animals, including man. The factors of determinate growth, high sensitivity of critical tissues, the absence of haploid mitosis in gametophytic development, and the lack of rapid somatic divisions preceding egg formation, should render animals much more vulnerable to low intensities of ionizing radiation.

References

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A Comparison of the Response of Normal and Hypothyroid Mice to Acute Whole Body Roentgen Radiation[1]

Thomas J. Haley, Samuel Mann, and Andrew H. Dowdy

School of Medicine, University of California, Los Angeles

In 1949 Blount and Smith (*1*) showed that premedication with thiouracil slightly decreased the mortality of mice subjected to acute whole body roentgen ray irradiation. This would indicate that the hypothyroid state was conducive to survival after roentgen ray irradiation. Shortly thereafter Patt *et al.* (*6*) reported significant decreases in radiation mortality in animals premedicated with cysteine. It was postulated that the beneficial effect

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